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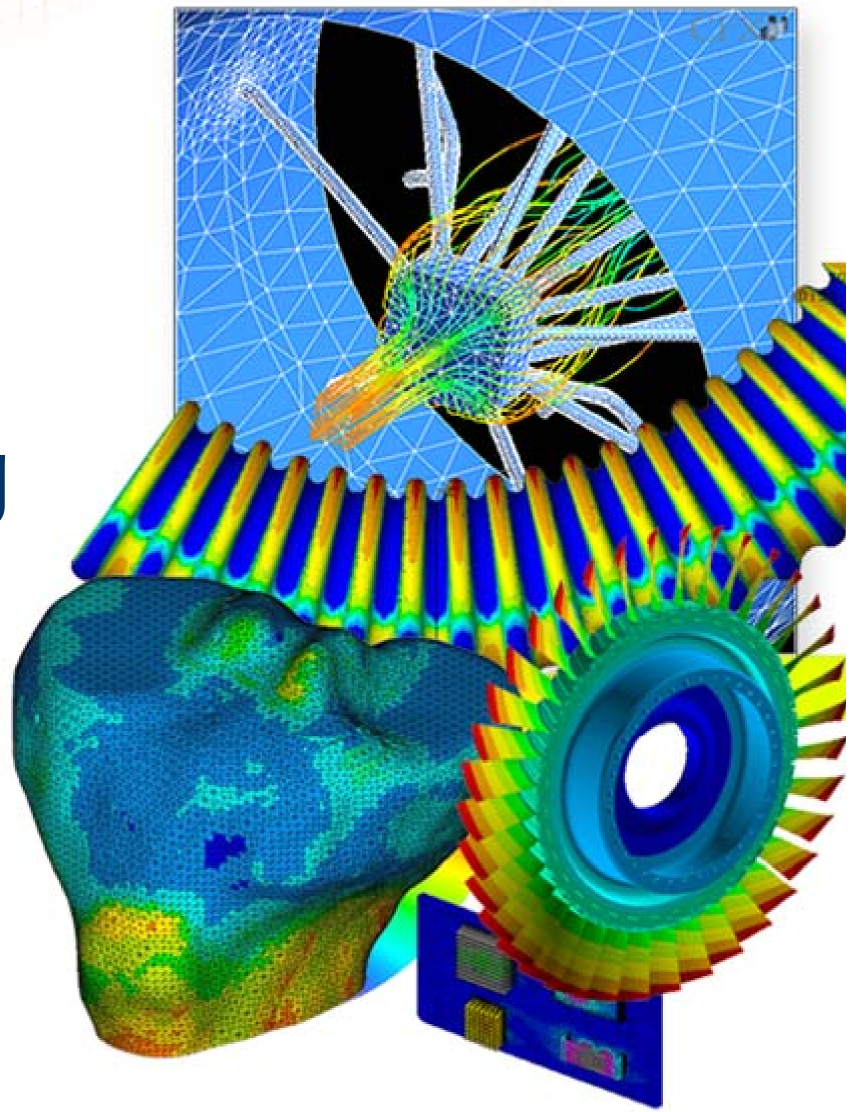
ENGINEERING ADVANTAGE

# Modeling Welded Connections ANSYS e-Learning



Peter Barrett

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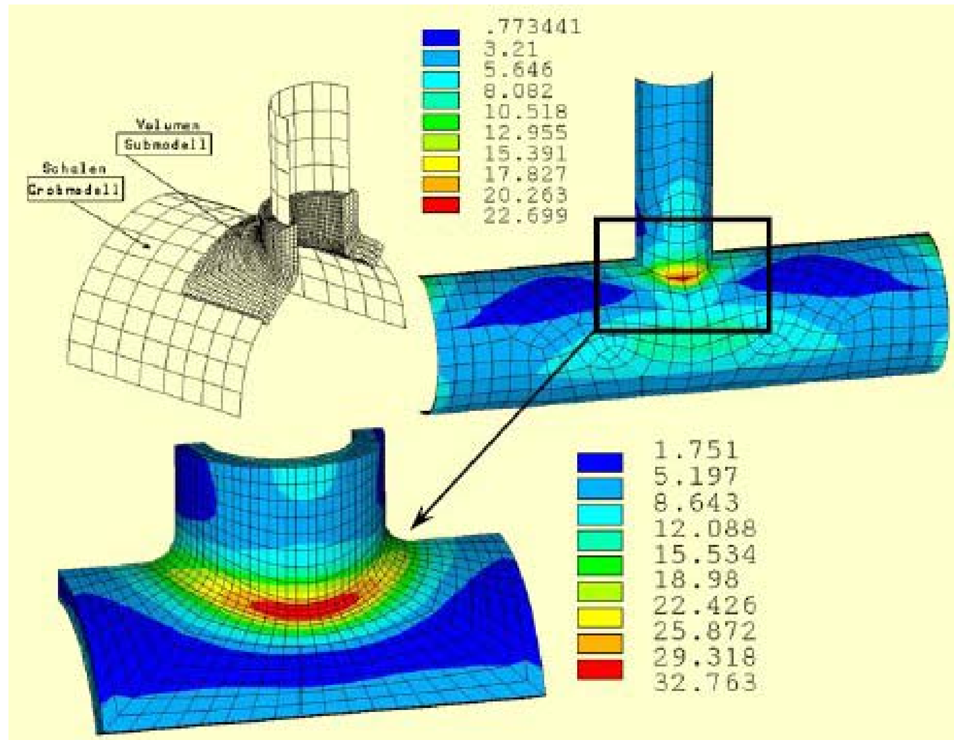
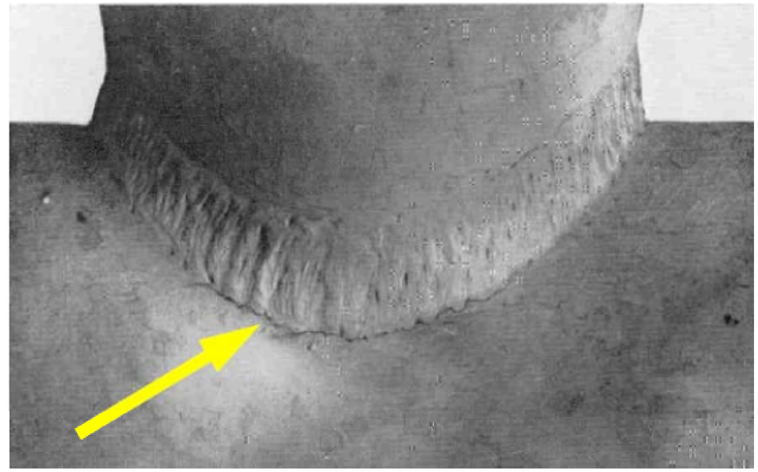
# Outline

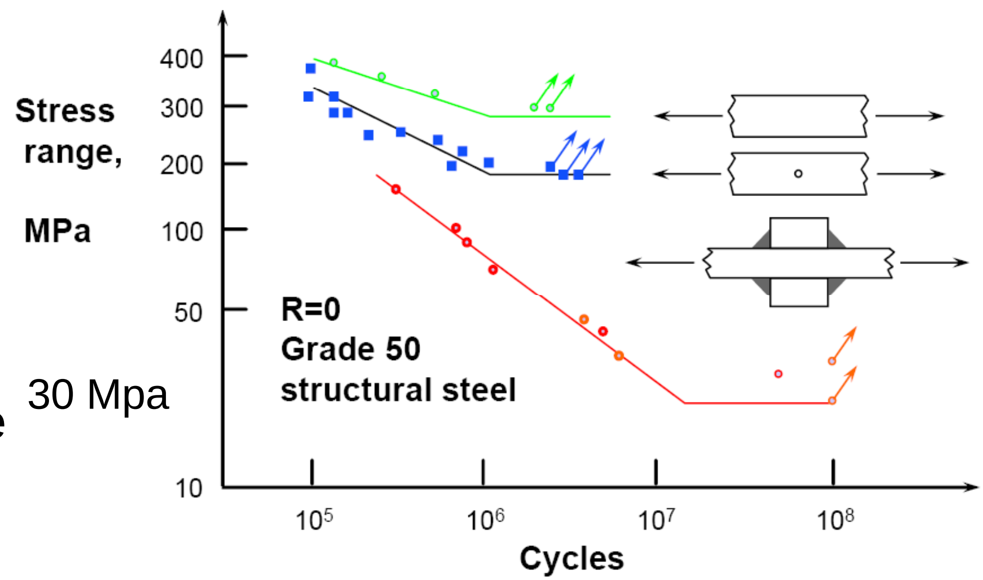
- The importance of weld stress prediction.
- Weld geometry and terminology.
- Failure due to fatigue.
- Methods for calculating weld stresses and how to use them
  - Nominal stress method.
  - Structural hot spot stress method.
  - Effective notch stress method.
  - Stress intensity at a crack tip.



# The Importance of Weld Stress Prediction

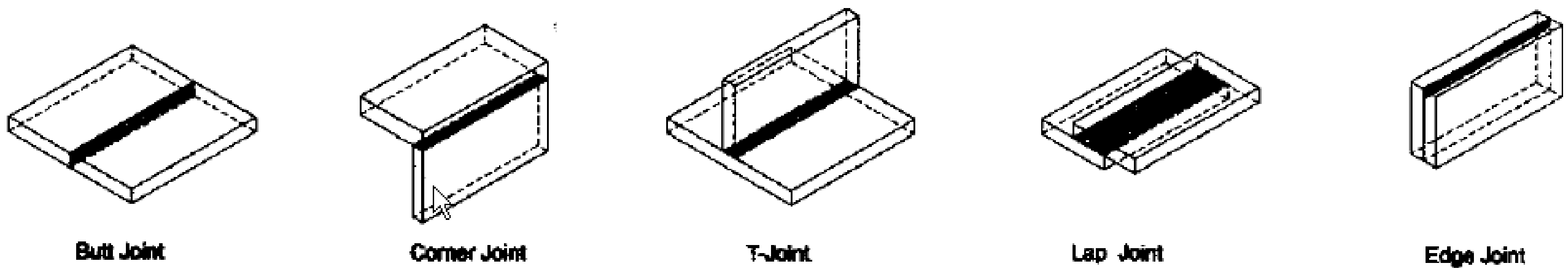
- Key features of welds:
  - Sharp section changes.
  - Local discontinuities.
  - High tensile residual stresses.
  - Crack initiation sites.
  - Material properties vary over weld cross section.
  - Geometry of weld cannot be modeled in detail.
- Consequences:
  - Relatively low fatigue strength.
  - Dominated by fatigue crack growth.
  - Fatigue life not increased by use of higher strength material.



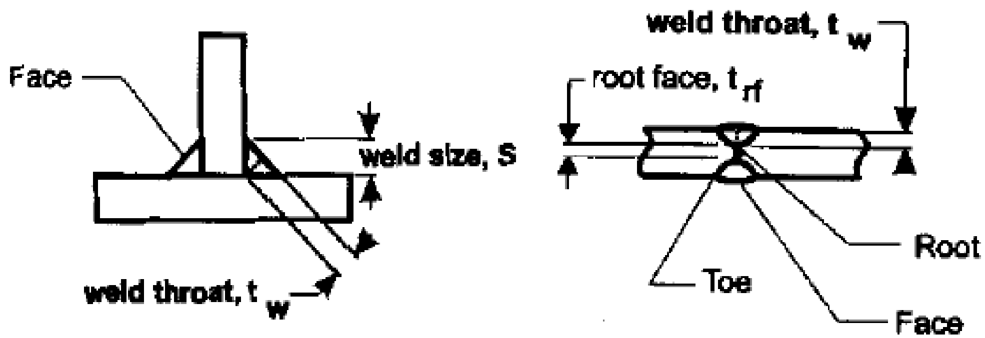


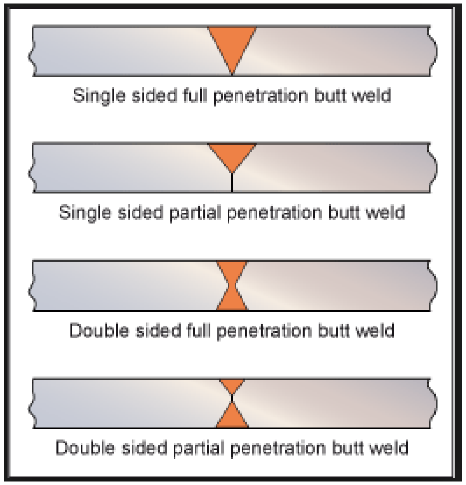
# Weld Geometry and Terminology

- Weld joints.
  - Weld joints are characterized by the geometry of the mating parts.
  - Five basic weld joint types:



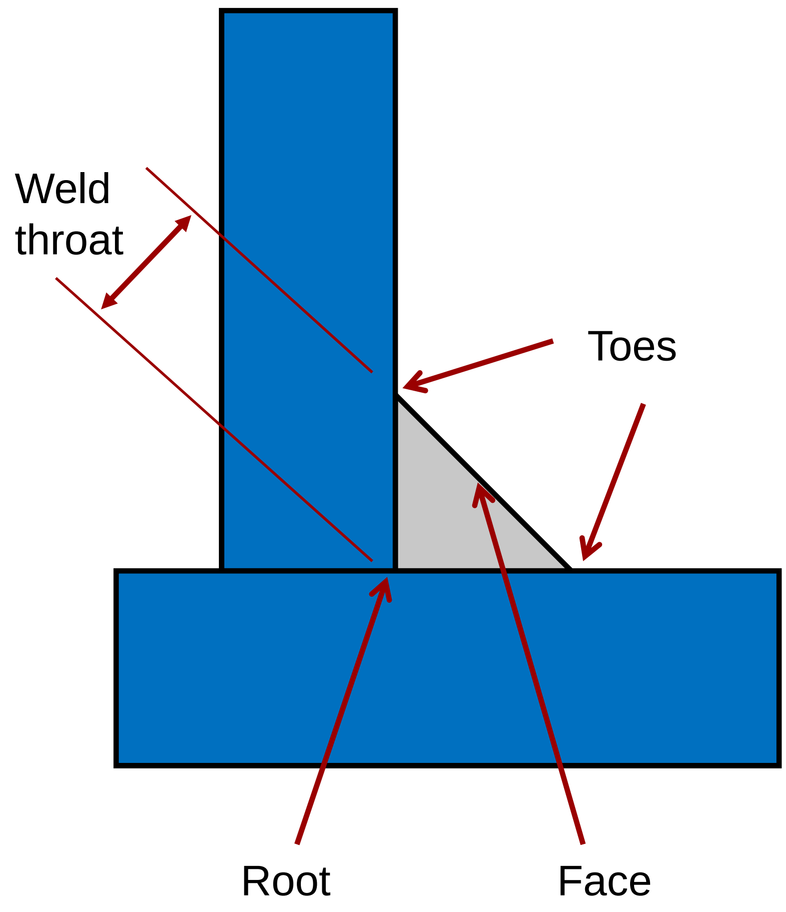

- Weld types.
  - The most common types of welds are fillet or groove.




  - Welds can be classified as complete or incomplete (partial) joint penetrated.

- Weld features.
  - Face:
    - The exposed surface of the weld.
  - Toe:
    - The point or line where the face meets the parent material.
  - Root:
    - The point in the weld joint where the weld metal ends.
  - Weld throat:
    - The minimum distance from the root to the face of the weld.
    - It is the minimum load bearing section and considered the effective area.



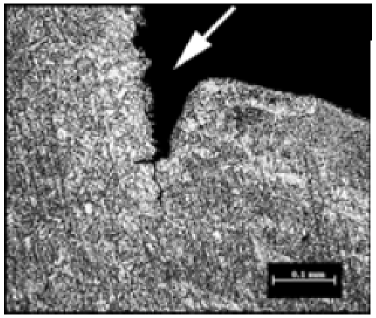
# Fatigue Failure in Welds

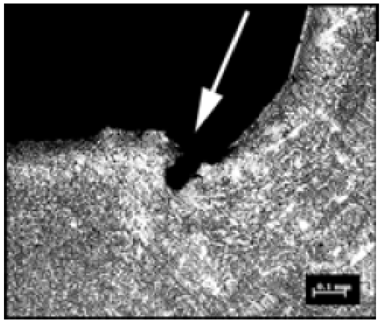
- The primary failure mechanism in welds is fatigue.
  - Fatigue is failure from cyclic loading.
  - The underlying mechanism in fatigue is the propagation of cracks.
  - Cracks are present from the welding process.

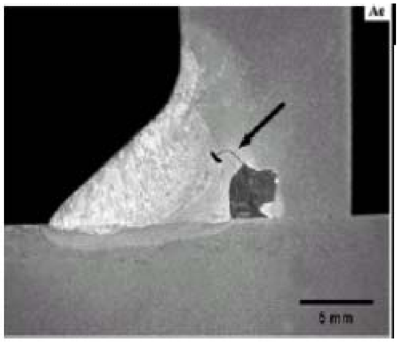
- Weld Life prediction due to fatigue is most often performed using two approaches both of which are available using ANSYS and NCODE:
  - S-N data.
    - Compare stress range to experimental life data (cycles to failure).
  - Linear elastic fracture mechanics.
    - Calculate stress intensity factor range at tip of existing initial crack and use to predict crack growth.

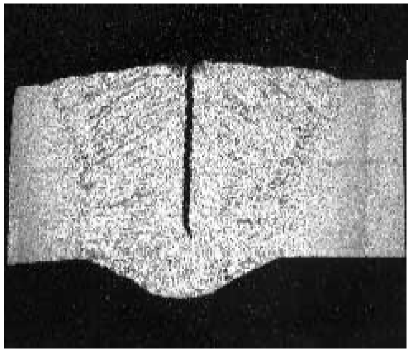
# Fatigue Failure in Welds

- Crack initiation in welds caused by:
  - Stress concentrations at weld toes and root.
  - Geometric and metallurgical discontinuities.
  - Weld defects:
    - Lack of fusion (cold lap):
      - Too little heat input or too rapid traverse of the torch.
    - Incomplete penetration:
      - Too little heat input or too rapid traverse of the torch.
    - Undercutting:
      - Thickness reduced at the toe.
    - Porosity:
      - Trapped gas.
    - Inclusions:
      - Trapped slag.
    - Small effective throat thickness.
    - Solidification cracking.







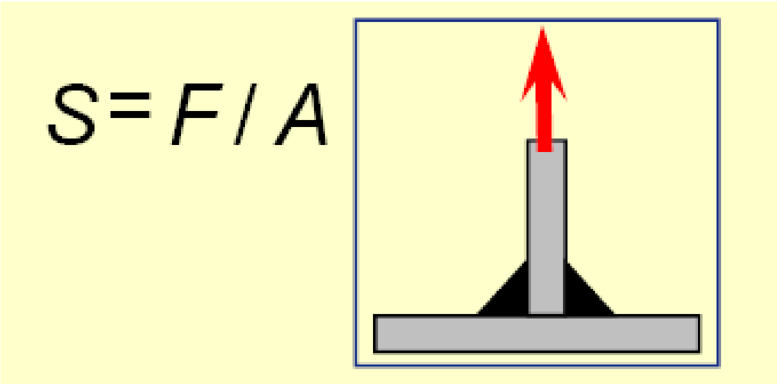
# Methods for Calculating Stress in Welds

- There are four methods generally used for calculated stress in welds:
  1. Nominal stress method.
  2. Structural hot spot stress method.
  3. Effective notch stress method.
  4. Stress intensity at a crack tip.

- The method used in assessing welded structure life depends on:
  - The nature of the problem.
  - If the method is valid for approval of a particular component.
  - If the welded design is catalogued in a welding standard.
  - If a conservative approach is acceptable.
  - The ability to create detailed finite element analyses of local weld regions.

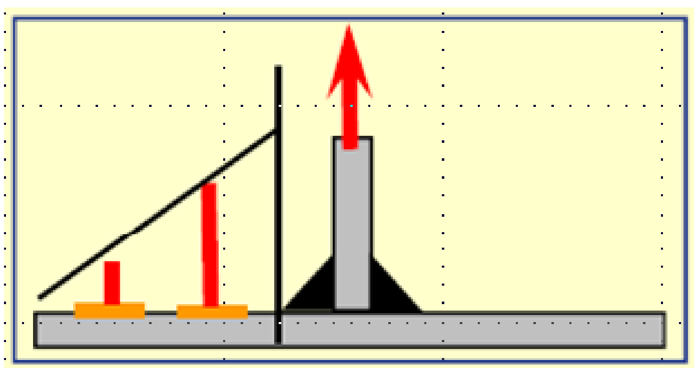
# Nominal Stress Method

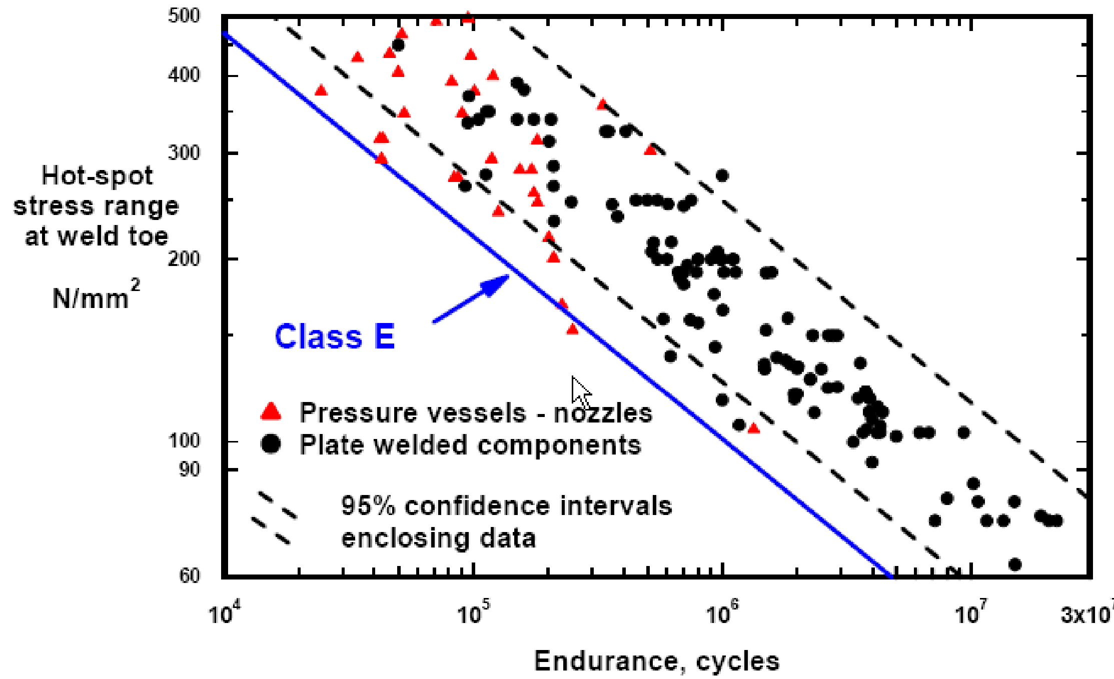
- Nominal stress method.
  - Classical analysis or hand calculation approach.
  - Stress calculated as section loads divided by net sections and bending moments divided by section moduli.
  - The focus of most welding standards.
  - Fillet welds and partial penetration groove welds are evaluated in terms of throat shear – the load transferred by the weld divided by the weld throat.
  - Considered a conservative approach.
  - Life prediction found using S-N fatigue data.



# Structural Hot Spot Stress Method

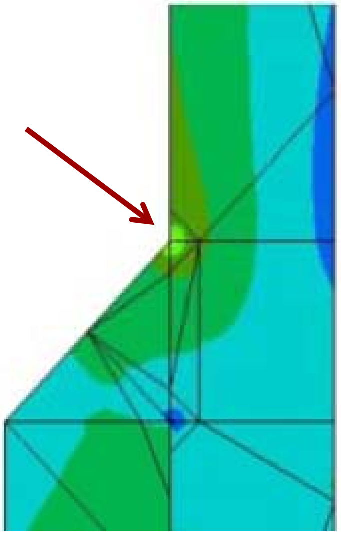
- Structural hot spot stress method.
  - It accounts for stress concentration effects, ignores the local notch effect of the weld toe.
  - Hot spot stress found by extrapolating stress from adjacent region to weld toe from FE analysis.
    - Various methods for extrapolating, such as along surface or through thickness.
  - S-N fatigue data based on hot spot stress range exists for some weld designs.





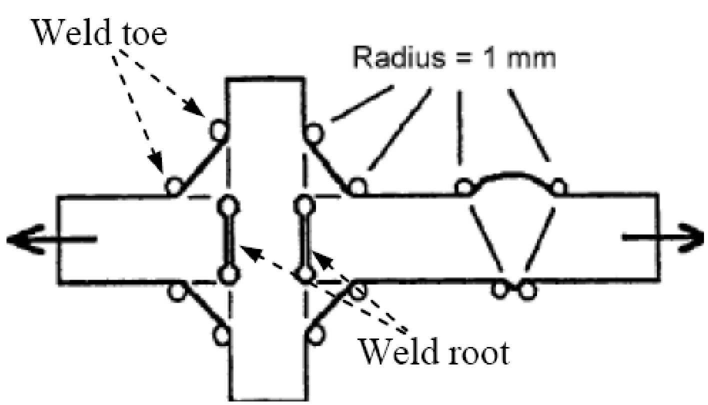
# Recognizing and Handling Singularities

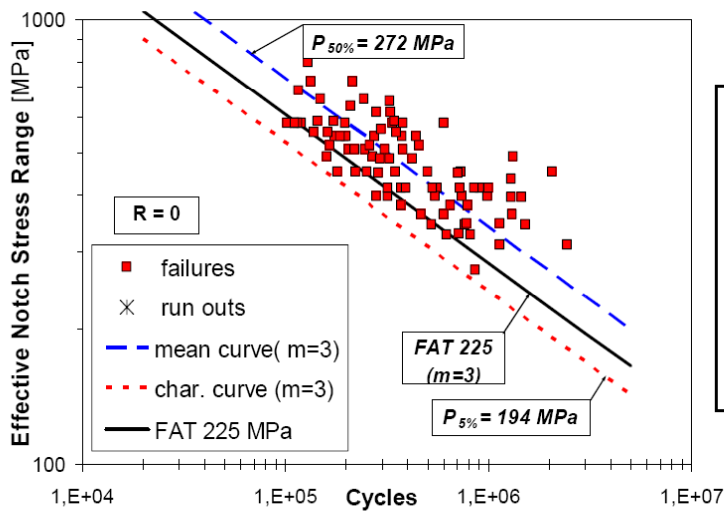
- The stress level at any re-entrant corner, such as can occur at the toe of a weld with no fillet radius, is theoretically infinite.
  - The stress will converge to infinity with mesh refinement.
  - Any assessment based on direct use of stresses at these locations is unsound.
- If FE model contains re-entrant corners:
  - Use nominal stress method, or
  - Extrapolate stress field to this location: hot spot approach.
- If fillet radii are used (effective notch method):
  - There is no singularity.
  - The radius will create a stress concentration, which results in a converged stress that can be used in life prediction calculations.



# Effective Notch Stress Method

- Effective notch stress method:
  - The effective notch stress is the stress at the weld toe radius obtained assuming linear elastic response.
  - To take into account variations in the weld shape, the real weld contour is replaced by an effective notch root radius of **1 mm**.
  - For thin structures (under 5 mm), a fictitious notch radius of 0.05 mm is recommended.
  - S-N curves exist that contain the notch stress range vs. cycles to failure.



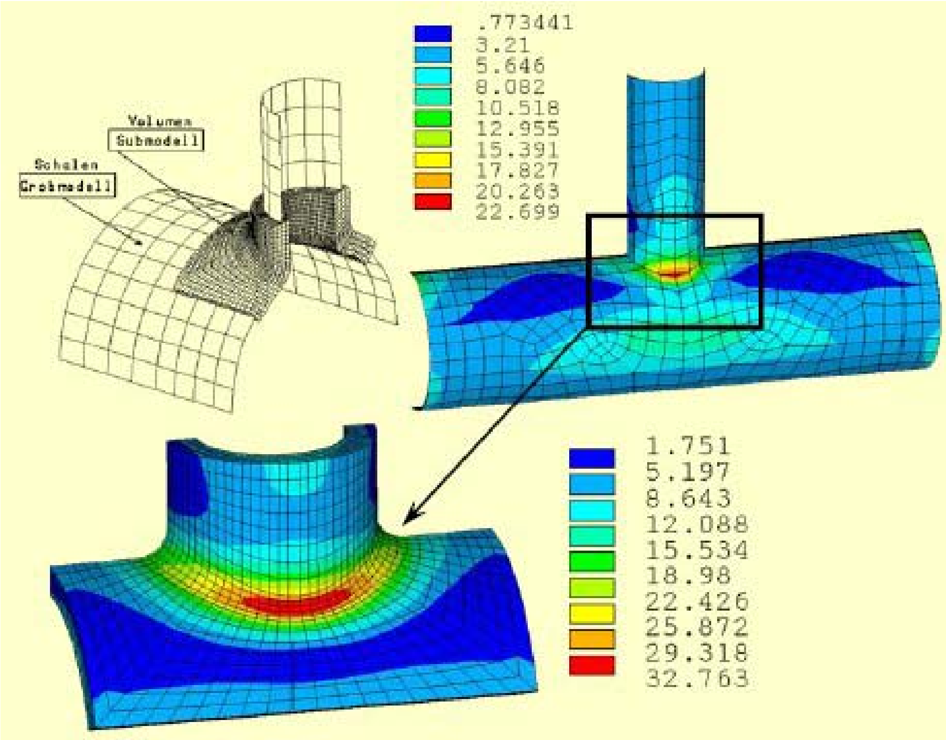

| |
|---|
| $R_{effective}$ = 1 mm ($K_t$=2.5) |
| $R_{mean}$ = 1.4 mm |
| $R_{(strd.deviation)}$ = 1.2 mm |
| $\theta_{mean}$ = 46° |
| $\theta_{(strd.deviation)}$ = 6.8° |
| Log $C_{mean}$ (m=3) = 13.6 |
| Log $C_{(strd.\ deviation)}$ = 0.23 |
| Nr of strd. Deviations = 1.92 |
| $FAT_{Pf50\%}$ = 272 MPa |
| $FAT_{Pf5\%}$ =194 MPa |

The value of 225 refers to a 5% failure probability at 2 million cycles with 225 Mpa notch stress

# 2D and 3D Weldment Models

- The solid model approach provides a more realistic representation of the weld region.
  - Typically, the weld region is included in the model.
  - If weld is not modeled, the same issues as shell modeling arise.

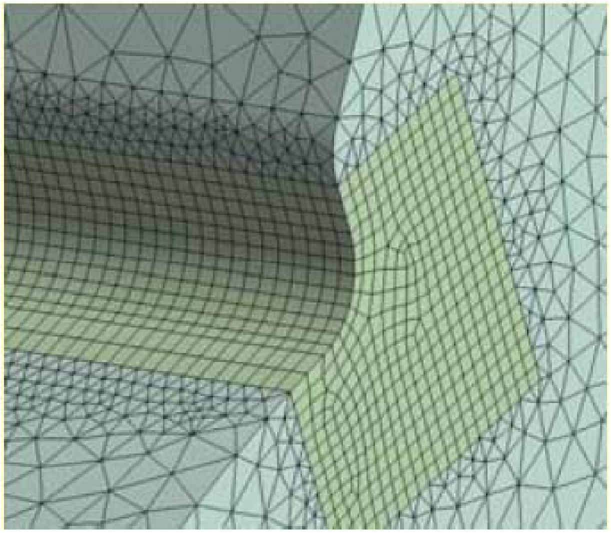
- Common procedure:
  - Create global model without welded detail – shell elements.
  - Create submodel with welded detail – solid elements.



# 2D and 3D Weldment Models

- 2D and 3D models can be used in all four weld stress methods:
  - Nominal stress can be found from far-field stresses.
  - If sharp discontinuities modeled at weld toes, hot spot stress can be evaluated.
  - If fillet radii are used at weld toes, effective notch stress is found.
  - If a weld defect is modeled, $K_I$ can be evaluated.

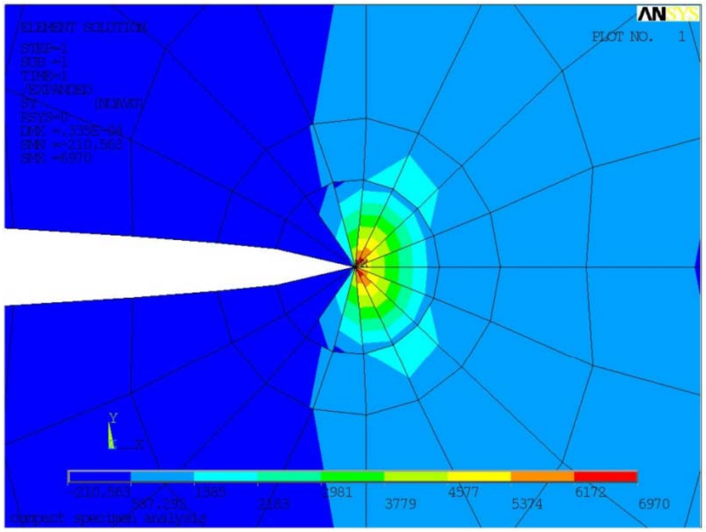
- The mesh density must be fine enough to predict accurate stresses.



# Stress Intensity at a Crack Tip

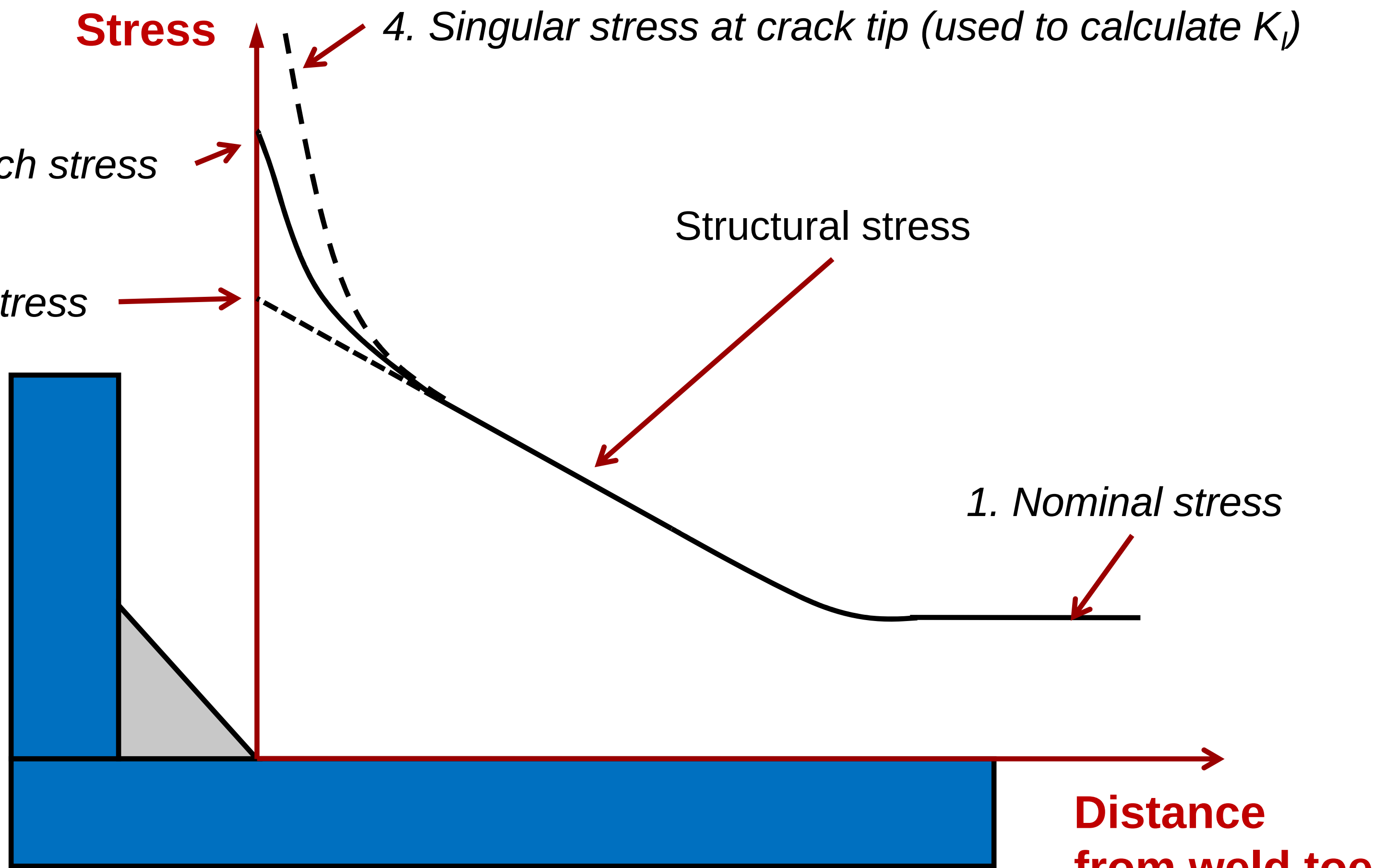
- Stress intensity at a crack tip:
  - Models a known crack size and location.
  - Requires a fine mesh near the crack tip.
  - Calculates stress intensity at the crack tip.
    - The stress is singular (tending to infinity) at the crack tip, thus the stress intensity factor, $K_I$, is required.
    - $K_I$ is a function of crack geometry and loading.
  - Methods of calculating stress intensity:
    - Special crack tip elements used with ANSYS ***KCALC*** command to determine $K_I$.
    - J-integral formulation.
    - Direct extrapolation method.
  - Analysis is repeated by extending crack perpendicular to the 1st principal stress a small distance and recalculating $K_I$.
    - Requires changing the local geometry and mesh – a significant effort.

$$\sigma_{yy} = \frac{K_I}{\sqrt{2\pi r}} \cos\frac{\theta}{2}\left(1 + \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right)$$



# Comparison of Stress Techniques

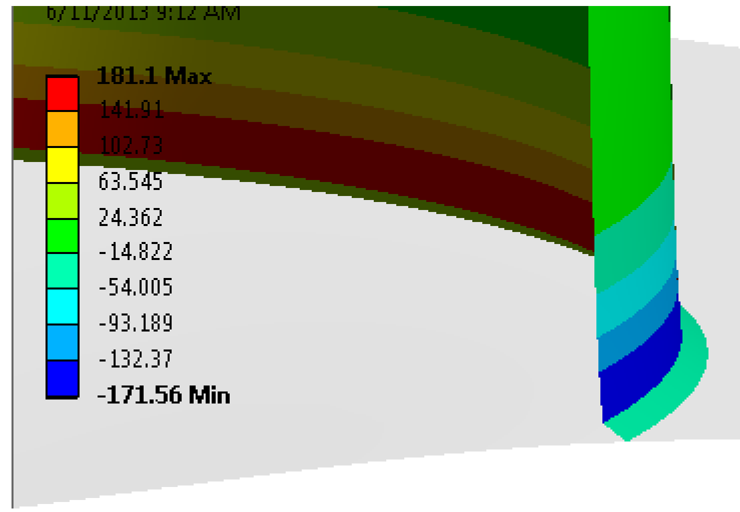
- An illustration of the comparison of the different stress calculation techniques:

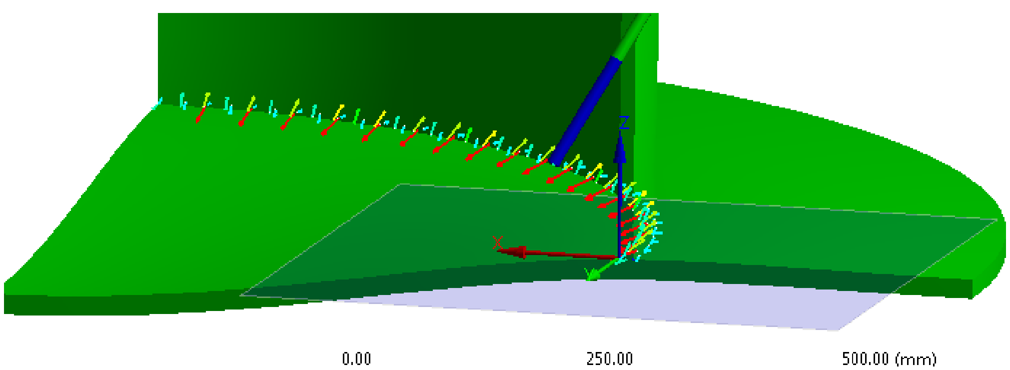


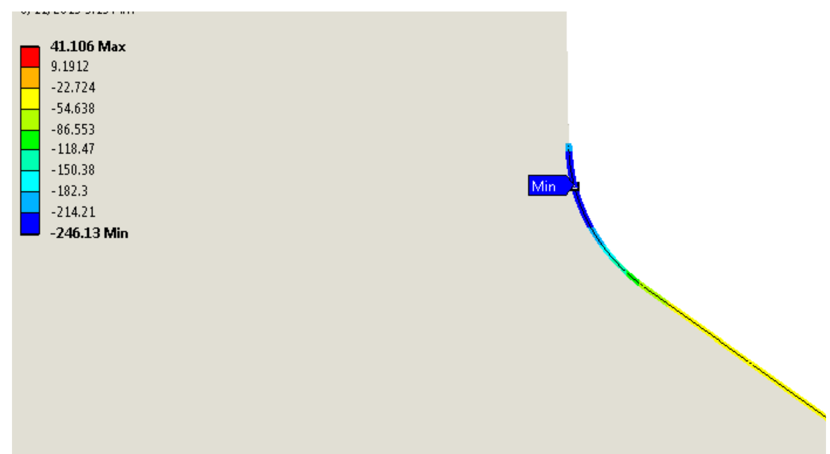
# Comparison of Stress Techniques

- An illustration of the comparison of the different stress calculation techniques:

- Our Example:
  - Est. Nominal Stress = 45 MPA
  - Est. Hot spot Stress = 171 MPA
  - Effective notch stress = 246 MPA



# Stress Techniques vs. S-N Data

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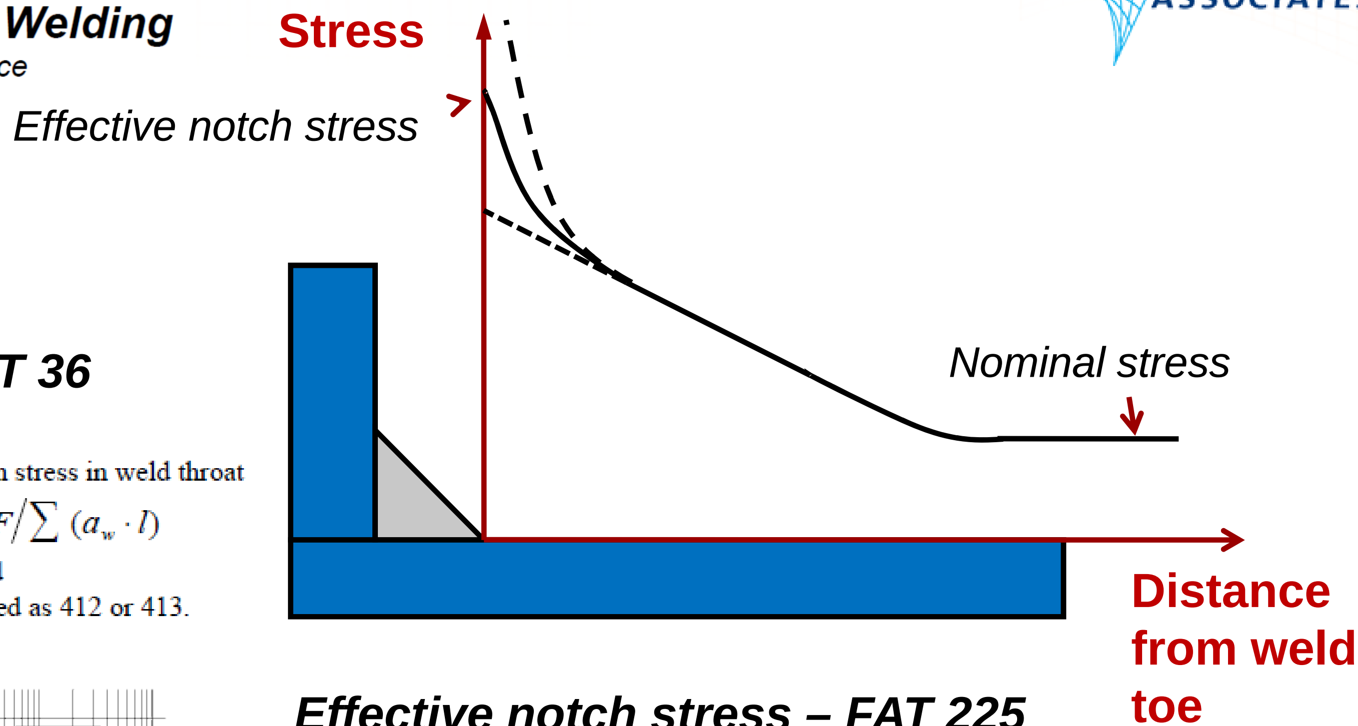
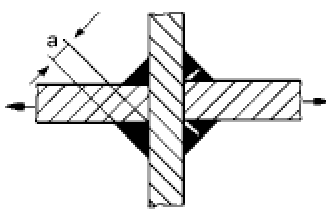
*A world of joining experience*




## *Nominal stress FAT 36*

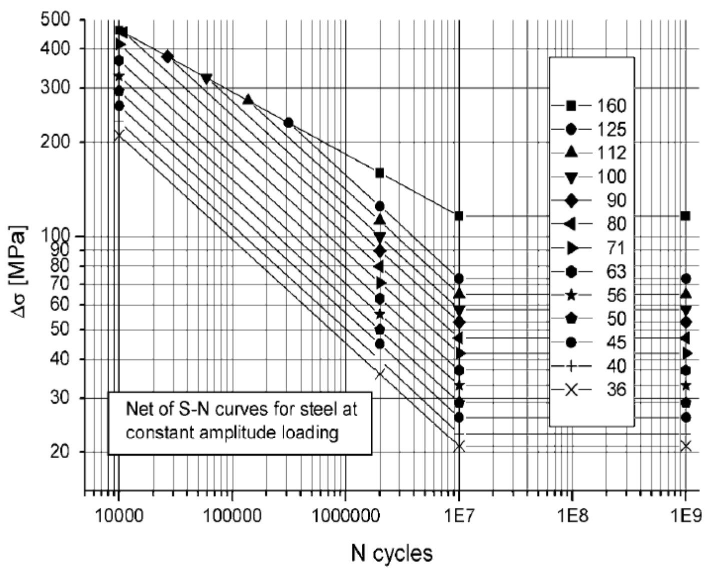


Analysis based on stress in weld throat

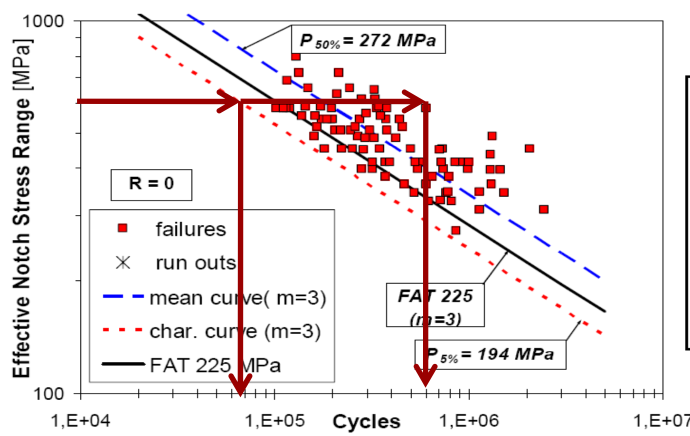
$$\sigma_w = F / \sum (a_w \cdot l)$$

l = length of weld

Also to be assessed as 412 or 413.




## *Effective notch stress – FAT 225*

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